Chemistry I

Nuclear Chemistry

Introduction

- Nuclear Chemistry deals with changes that occur in the nucleus(nuclei) naturally or by humans.
  - Terms:
    - Atomic nuclei are made of protons and neutrons
    - The protons and neutrons of an atom are collectively called nucleons
    - Atoms in Nuclear Chemistry are called nuclides and are identified by the protons and neutrons in the nucleus

Introduction

- Nuclides are represented in several ways:
  - Isotopic symbols: these include the mass #, atomic # and the element symbol.
  - $${}^{238}_{92}U$$

Isotopic Symbol

Mass number

$$^{31}_{15}P$$

Element symbol

Atomic number

Introduction

- A different way includes the same numbers but on different sides of the symbol:

$$_{92}U^{238}$$

Introduction

- A second way is the abbreviated isotopic symbol. This uses the symbol then a dash (-) and the mass #

  » Looks like this: U-238

Element symbol

dash

Mass Number

Nuclear Stability

- What really makes an atom radioactive?
  - Lets begin with an atoms nucleus.
    - Strong nuclear forces hold everything together in the nucleus (p^+ and n^0)
    - Nuclear binding energy is the energy released when a nucleus is formed by the coming together of the protons and neutrons (nucleons).
      - Another way to put this is: how much energy does it take to break a nucleus of an atom apart

Mass defect

- Scientists saw something strange about whole atoms and their parts
- When the individual parts of an atom were added up, some of the mass disappeared.

Proof of mass defect

- The proof is in Einstein's $E=mc^2$. This shows the relationship between energy and matter.
- What happen to the mass?
- when the neutrons and protons came together to form a nucleus, some of the mass was converted to energy.

Nuclear Stability

- The nuclear properties of an atom depend on the number of p^+ and n^0 in the nucleus.
- The number of p^+ and n^0 in the nucleus can cause an atom to become unstable.
- When this happens the nucleus readily emits radiation
- The nucleus does this to become more stable and to reduce energy.
- The atom is said to be *radioactive*

Nuclear Stability

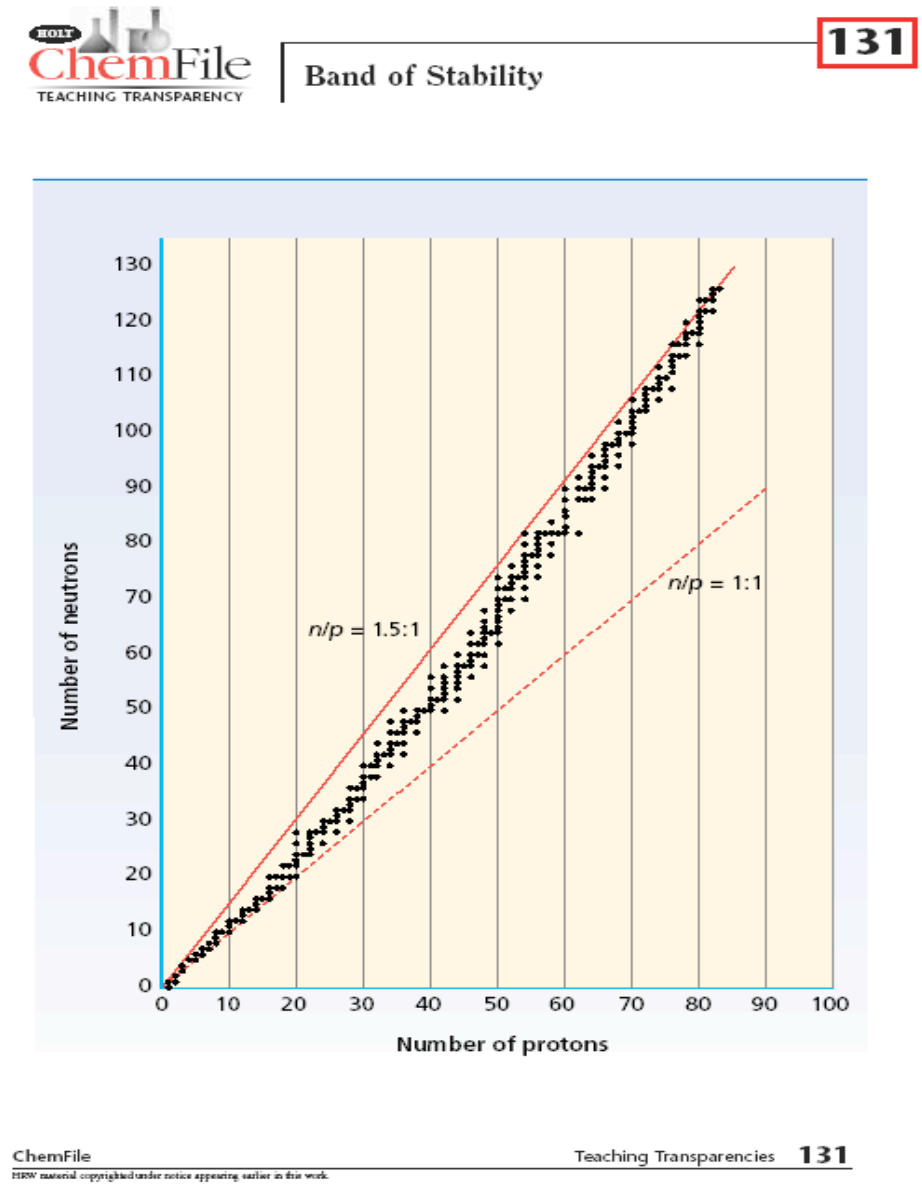
- This spontaneous release from a nucleus is called nuclear decay.
- This generally occurs only in elements with atomic number greater than 80
- Once this decay process occurs, a new element is created or a non-radioactive isotope of the same element.
- Elements will change until they are stable.

Nuclear Stability

- Predicting nuclear stability
  - Can be predicted by looking a the ratio between neutrons and protons in a particular nucleus.
  - That neutron-proton ratio is about 1:1 for smaller atoms and increases to 1.5:1 for larger atoms.

A graph of the number of neutrons v. the number of protons

The curve is known as the band of stability



Nuclear Stability

- The reason for the instability appears to be a battle between electrostatic forces and nuclear forces in the nucleus
  - Protons repulse each other
  - Strong nuclear forces hold protons together
  - The nuclei become unstable when the electrostatic forces over come the nuclear forces

Nuclear Stability

- There is a theory that the particles in the nucleus are in energy levels.
  - The most stable nuclei are 2, 8, 20, 28, 50, 82, or 126. *(these are called magic numbers)*
  - Greatest stability when nucleons are paired
    - In other words a neutron with a proton

Nuclear Reactions

- These reactions are different than ordinary chemical reactions
- Nuclear reactions will produce a new element and a large amount of energy which we call radiation
- These reactions involve changes in the nucleus of an atom

Nuclear Reactions

- Transmutation is a change in the nucleus due to a change in the number of protons
  - Once the number of protons changes; the element changes to a different element

Nuclear reactions

- Example:

$$ {}^{212}_{84}Po \rightarrow {}^{4}_{2}He + {}^{208}_{82}Pb $$

Nucleus of Po atom lost 2 protons and 2 neutrons

Alpha particle ejected

Lead (Pb) was the new; more stable element produced during this change

Radioactive decay

- In 1896, Henri Becquerel found that some compounds of uranium would expose protected photographic film. Since these were unknown rays they were called X-rays.
- The unknown rays were coming from the uranium happened naturally

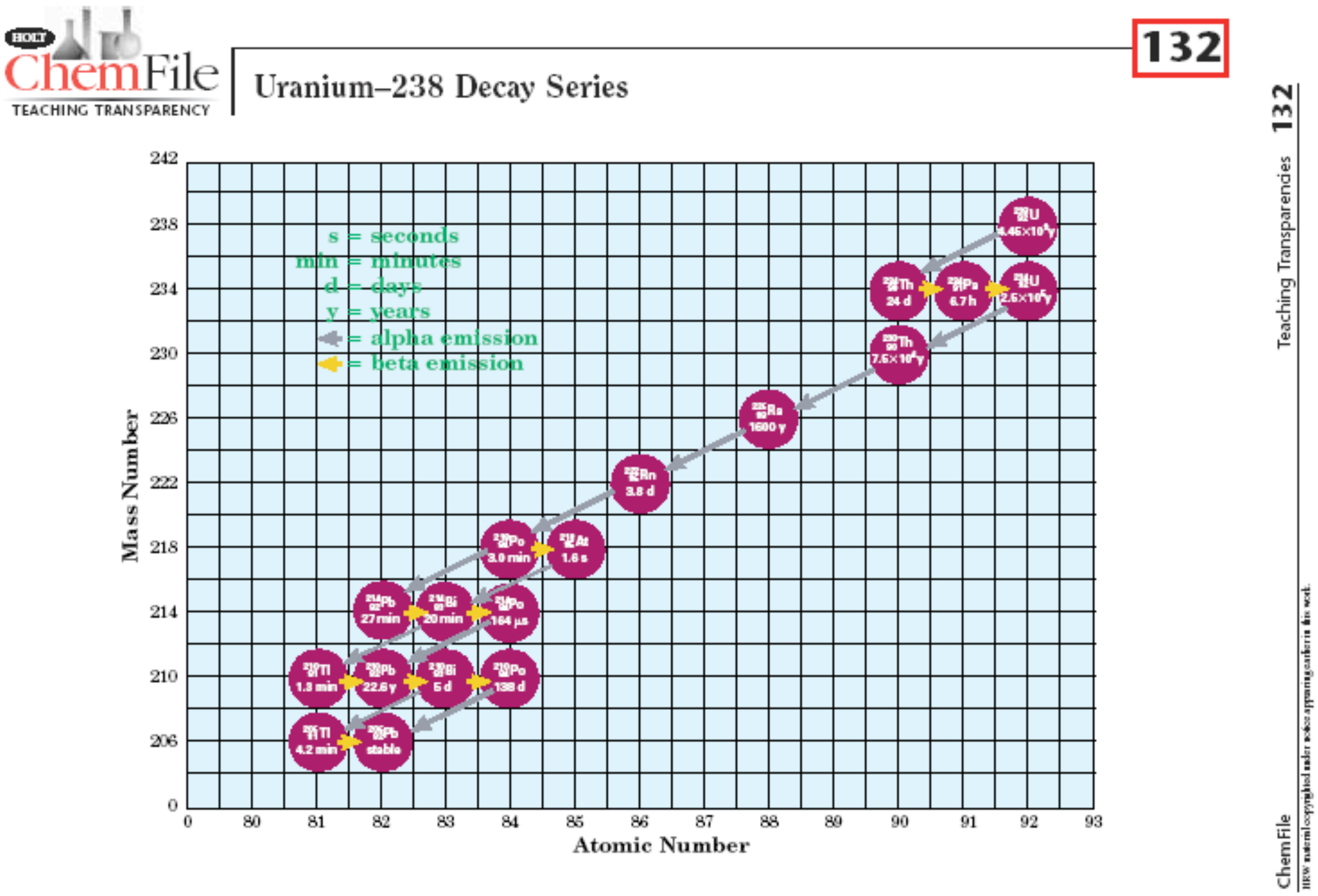
Radioactive decay

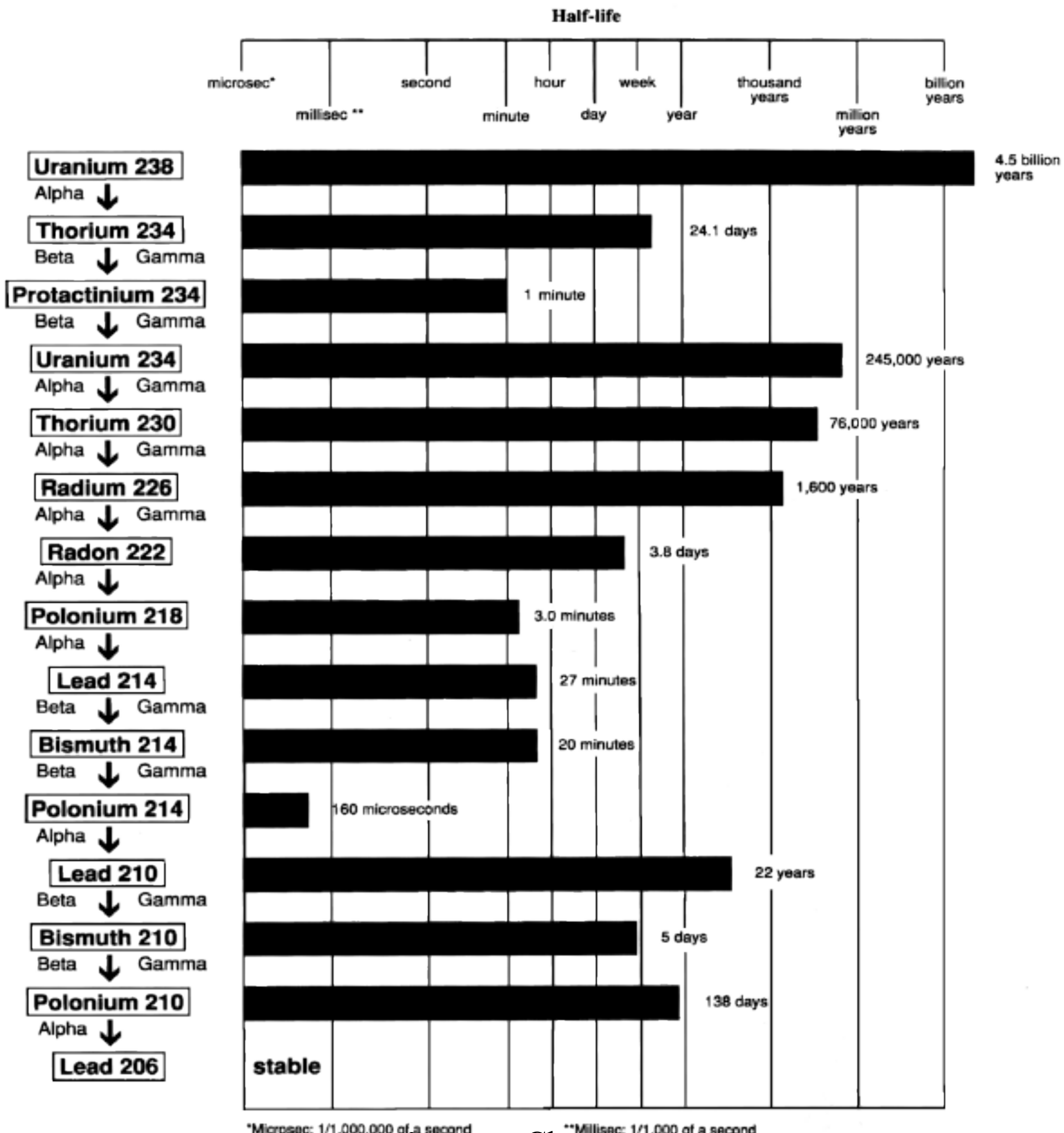
- Radioactive decay is the spontaneous breakdown of the nucleus of an atom into a smaller (lighter) nuclei.
- During this change, energy and subatomic particles come of the nucleus of the unstable atom.
- A radioactive nuclide is an unstable nucleus that undergoes radioactive decay.

Radioactive decay

- The path(steps) that a radioactive element takes to change to a stable element is called a decay series.
- Terms:
  - The heaviest nuclide of a decay series is called the *parent nuclide.*
  - The nuclides produced by the decay of the parent nuclide are called *daughter nuclides*

This is the decay series for uranium




Half-life
microsec*
millisec **
second
minute
hour
day
week
year
thousand years
million years
billion years
Uranium 238
Alpha
4.5 billion years
Thorium 234
Beta Gamma
24.1 days
Protactinium 234
Beta Gamma
1 minute
Uranium 234
Alpha Gamma
245,000 years
Thorium 230
Alpha Gamma
76,000 years
Radium 226
Alpha Gamma
1,600 years
Radon 222
Alpha
3.8 days
Polonium 218
Alpha
3.0 minutes
Lead 214
Beta Gamma
27 minutes
Bismuth 214
Beta Gamma
20 minutes
Polonium 214
Alpha
160 microseconds
Lead 210
Beta Gamma
22 years
Bismuth 210
Beta Gamma
5 days
Polonium 210
Alpha
138 days
Lead 206
stable
*Microsec: 1/1,000,000 of a second
**Millisec: 1/1,000 of a second

Types of radioactive decay

- There are 3 general types of nuclear decay we will consider:
  - 1) alpha emission- the changes in the nucleus cause an alpha particle to be ejected from the nucleus.
    - An alpha particle is a helium atom w/o electrons; it has 2 protons and 2 neutrons
    - This type of emission is mostly found in heavy atoms
    - This emission will reduce the mass by 4 amu and the atomic number by 2 protons. Hence the new element's atomic number will be 2 less than the original decaying element.
    - The symbol used for alpha emission is

Types of radioactive decay

- 2) beta emission-occurs when atoms of elements above the band of stability have too many neutrons.
  - a neutron breaks into a proton and an electrons
    - The proton stays in the nucleus
    - The electron is ejected at high speed out of the nucleus
    - This type of emission increases the atomic number by 1 and the mass number remains the same
    - The symbol for a beta emission is

Types of radioactive decay

- Gamma emission-occurs when other types of decay happen in the nucleus.
  - Gamma radiation is a type of high energy short wavelength electromagnetic energy related to x-rays.
  - This is thought to occur when nuclear particles move within the energy levels in the nucleus
  - The symbol for gamma release is [illegible]

Radioactive Nuclide Emissions

Type	Symbol	Charge	Mass (amu)
Alpha particle	$^{4}_{2}He$	2+	4.002 60
Beta particle	$^{0}_{-1}\beta$	1–	0.000 5486
Positron	$^{0}_{+1}\beta$	1+	0.000 5486
Gamma ray	γ	0	0

Half-life

- **Half-life:**
  - Radioactive nuclides don't decay after a given time; they decay whenever they want.
  - The decay during a given time interval with a special probability.
  - To tell this probability of decay, the half-lives of all nuclides are given.

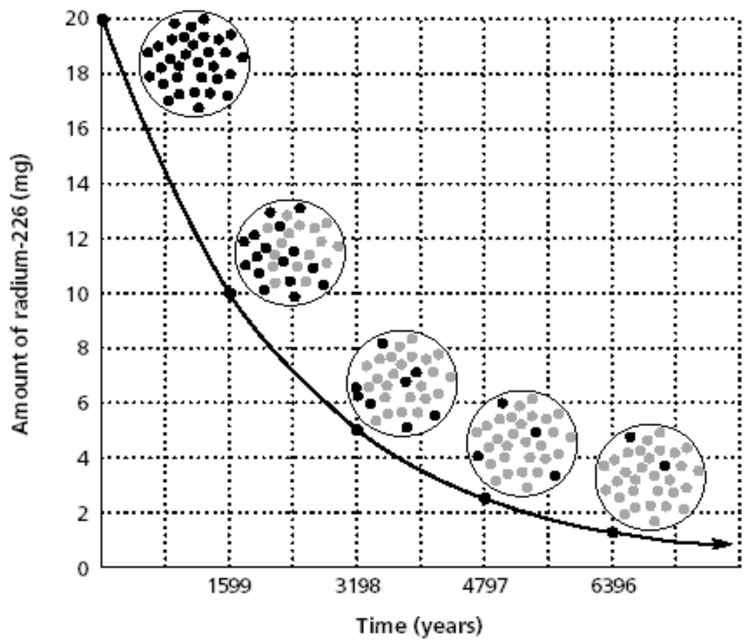
Half-life

- The half-life of a radioactive nuclide is the time for half of the number of atoms to decay.
- The half-life for different nuclides can range from a few nanosecond (10^{-9} s) up to millions of years (the longest half-life is more than 10^{20} years).
- Stable nuclides, since they do not decay, do not have a half-life.

Some half-life examples

- **U 238:** 4.47*10^9 years
  Th 234: 24.1 days
  He 4: Stable
  Pa 234: 6.7 hours
  C 11: 20.3 minutes
  B 11: stable
  U 235m: 26 minutes
  U 235: 7.04*10^8years
  Xe 140: 13.6 seconds
  Pd 112: 21 hours
  Po 212: 299 nanoseconds

Rate of Decay



Artificial Transmutation

- Artificial nuclides are radioactive nuclides not found in nature.
- These nuclides have to be made by humans.
- This is done by bombarding stable nuclei by other atomic type particles.
- Transuranium elements are those elements that have an atomic number greater than 92.
  - These are all radioactive and human-made.

Radiation Exposure

- Radiation penetration
  - We are concerned about types of radiation penetration:alpha, beta and gamma.
    - Alpha particles have a large mass and a (+)-charge
      - Therefore they have low penetrating power
        - » They cannot penetrate skin
        - » Can only travel a few centimeters in air
        - » They can be stopped by a sheet of paper
        - » These particles CAN cause tissue damage if inhaled or ingested

Radiation Exposure

- Beta particles have little mass and travel at close to the speed of light
  - They have 100 times the penetrating power of an alpha particle.
  - They can travel a few meters in air
  - These can be stopped by lead or glass
- Gamma rays are pure energy
  - They have the greatest penetrating power.
  - These are the most dangerous
  - They require thick lead and/or concrete to stop them

Radiation Exposure

- The problem with exposure to radiation is
  - Damages organs
  - Damages DNA in cells
  - These can lead to long term diseases such as cancer

Nuclear Fission

- Nuclear fission is the splitting of atoms
  - When atoms are split, tremendous amounts of energy are released from the nucleus
  - A very heavy nucleus splits into two smaller more stable nuclei of smaller mass.
  - When this happens some of the mass is converted into energy (atomic weapons).

Nuclear Chain Reactions

- When a U-235 atom is bombarded (shot) with a neutron the result is two smaller nuclei (Kr-93 and Ba-140) and 3 more neutrons + a ton of energy.
- This is called a chain reaction.
- The definition of a chain reaction is a reaction in which the material that started the reaction is a product and can continue the reaction.

Nuclear Chain Reactions

- If this reaction is left uncontrolled, you can get an explosion (nuclear weapons)
- In order to get a chain reaction to continue there has to be a certain amount of that material.
- The amount of nuclide needed to sustain a nuclear chain reaction is called the *critical mass*

Nuclear Chain Reactions

- Nuclear reactors us a controlled version of a chain reaction to produce heat.

Nuclear Chain Reactions

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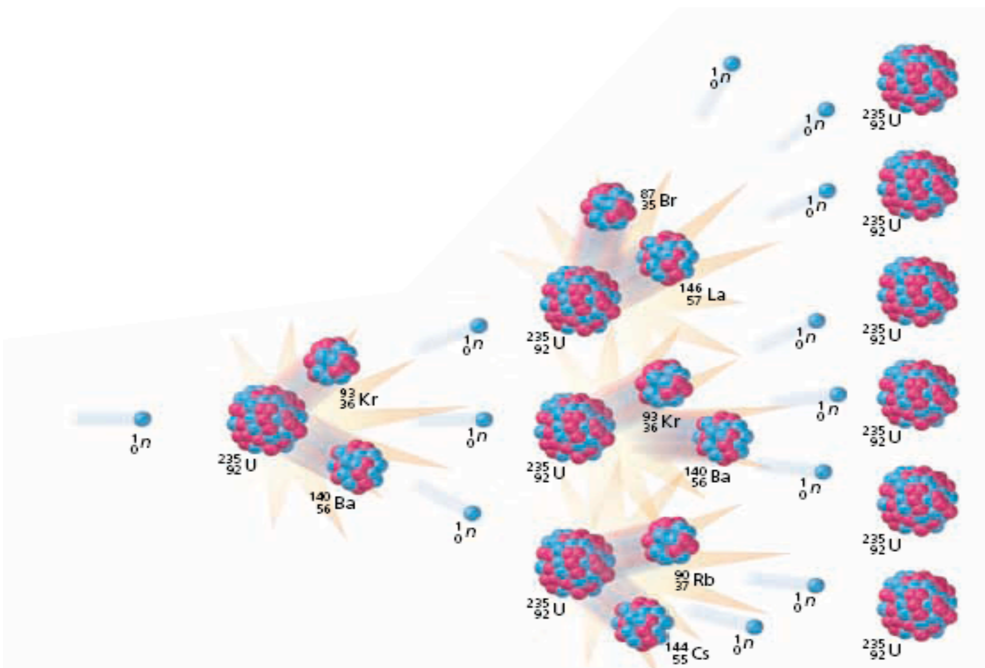
Nuclear Chain Reaction 134



Fission induction of uranium-235 by bombardment with neutrons can lead to a chain reaction when a critical mass of uranium-235 is present.

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Nuclear Chain Reactions

- The nuclear equation for the splitting of U-235 is:

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{93}_{36}Kr + {}^{140}_{56}Ba + 3\,{}^{1}_{0}n $$

Nuclear Fusion

- Nuclear fusion is the combining of atomic nuclides to form new elements
- So lighter nuclei combine to make bigger heavier more stable nuclei
- Again large amounts of energy are released

Nuclear Fusion

- The source of energy for the sun is a nuclear fusion reaction
- 4 hydrogen nuclei under extreme pressure and heat make helium nuclei
- The reaction looks like this:

$$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{+1}\beta$$

a positron

radon

- Radon is a natural product of the decay of uranium found in the earth
- Radon is a Nobel gas and does not react with anything
- That's the problem: it does not react and being a gas it can go wherever it wants to

Radon Characteristics

- colorless.
- odorless
- tasteless
- a radioactive gas

Radon Characteristics

- Radon comes from the natural (radioactive) breakdown of uranium in soil, rock and water and enters into the air you breathe
- Radon can be found all over the U.S.

radon

- Radon gas decays into radioactive particles that can get trapped in your lungs when you breathe.
- As they break down further, these particles release small bursts of energy.
- This can damage lung tissue and lead to lung cancer over the course of your lifetime.
- Not everyone exposed to elevated levels of radon will develop lung cancer.
- And the amount of time between exposure and the onset of the disease may be many years.

HOW DOES RADON GET INTO YOUR HOME?

- . Radon is found in nearly all soils.
- It typically moves up through the ground to the air above and into your home through cracks and other holes in the foundation.
- Your home traps radon inside, where it can build up.
- Any home may have a radon problem.
- This means new and old homes, well sealed and drafty homes, and homes with or without basements.

HOW DOES RADON GET INTO YOUR HOME?

- Radon from soil gas is the main cause of radon problems.
- Sometimes radon enters the home through well water
- In a small number of homes, the building materials can give off radon, too.
- However, building materials rarely cause radon problems by themselves.

Uncertainty

- Like other environmental pollutants, there is some uncertainty about the magnitude of radon health risks.
- However, we know more about radon risks than risks from most other cancer-causing substances.

Other sources of information

A Citizen's Guide to Radon

- U.S. EPA 402-K02-006, Revised September 2005
- http://www.epa.gov/radon

- **EPA's Web site at www.epa.gov/iaq/whereyoulive.html**